Mapping Evapotranspiration with Satellite Products

NASA Remote Sensing Training
Norman, Oklahoma, June 19-20, 2012
Presented by Cindy Schmidt (ARSET)
with contributions from
David Toll and Rick Allen

ARSET

Applied Remote SEnsing Training

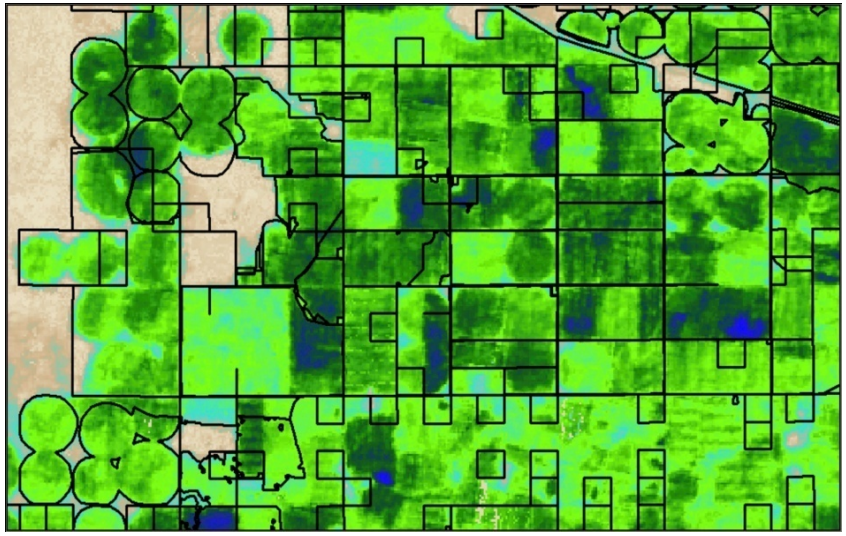
A project of NASA Applied Sciences

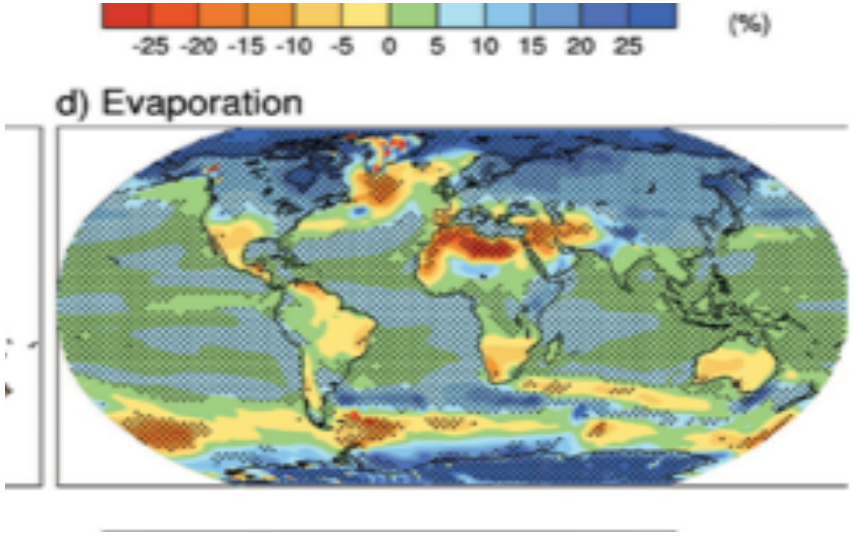
Overview

- Benefits and opportunities of using remote sensing for ET
- Methods of deriving ET using remote sensing:
    - Challenges
    - Applications of ET
    - Web based tools for accessing ET.
- Conclusions

Consumptive Water Loss Through Evapotranspiration

- Hydrological information on irrigation efficiency and water withdrawals from evapotranspiration are difficult to measure and hard to obtain.
- Evapotranspiration (water loss) from the land surface is spatially complex and is conducive for estimation using remote sensing.





Source: David Toll, NASA Goddard Space Flight Center

IPCC

Observational ET Challenges:

In-situ measurements:

Closure of the water balance at Flux towers is a significant problem. In-situ FLUXNET measurements are Not uniformly distributed around the Globe.

Remote Sensing:

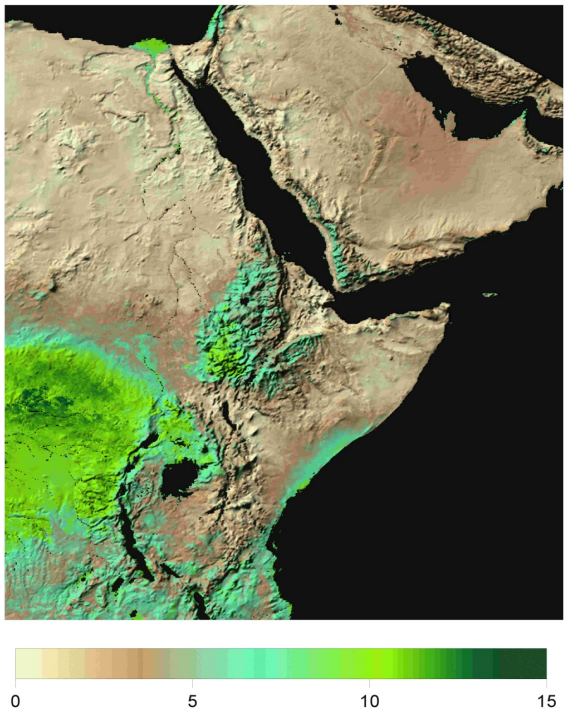
-High resolution data are needed to develop information for agricultural applications.

-Thermal IR sensor data are needed on an on-going basis. Disruptions in input data affect the quality of the product

Source: Rick Allen, University of Idaho

Opportunities for Mapping ET Using Remote Sensing

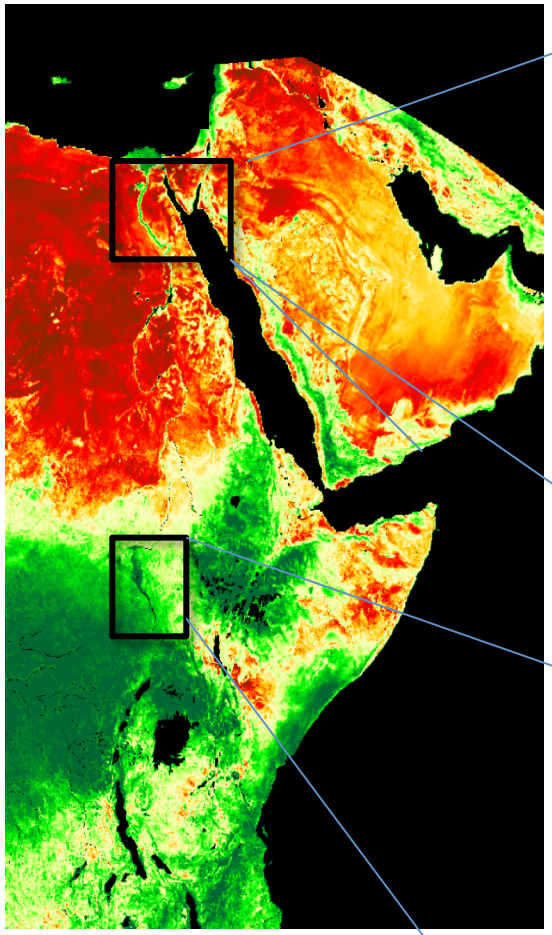
- Strong interest in consumption-based estimates of the water balance. ET can be a core product for water management applications.
- Contribute to informed discussion of transboundary water issues.
- Remote sensing is becoming a viable option for mapping ET with several techniques and new data bases .
- Need for improving *in situ* measurement and remote sensing validation.



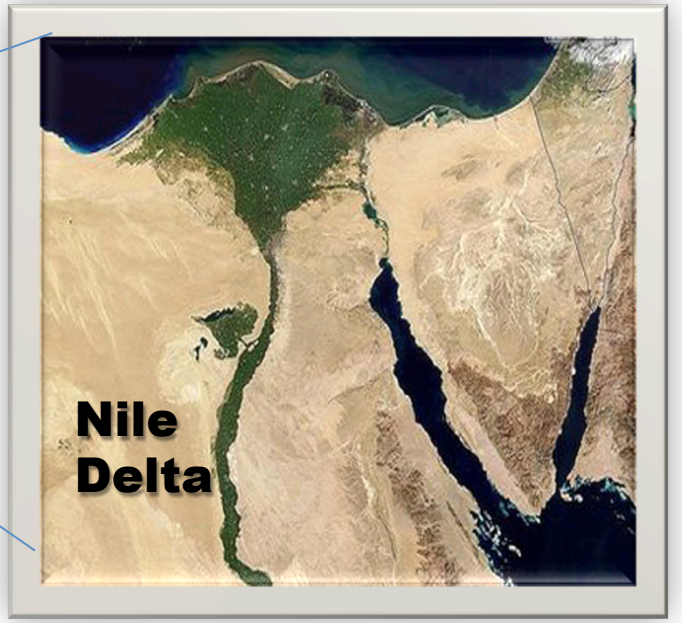
Source: David Toll, NASA Goddard Space Flight Center

Remote Sensing Products and tools for Measuring Consumptive Water Loss and Evapotranspiration

- Remote sensing of ET primarily from using satellite <u>infrared</u> data
  - Meteosat (~10 km)
  - MODIS (~1 km)
  - Landsat (~100 m)
- Several ET remote sensing algorithms
  - 'ALEXI' (Two Source)
  - 'SEBAL/METRIC'
  - 'SEBI/SEBS'
- Additional satellite ET remote sensing capabilities from SMAP, VIIRS & GRACE
- When normalized with 'Potential ET' provides index of drought
- When combined with modeling (e.g., 'LDAS') tools may provide predictions.

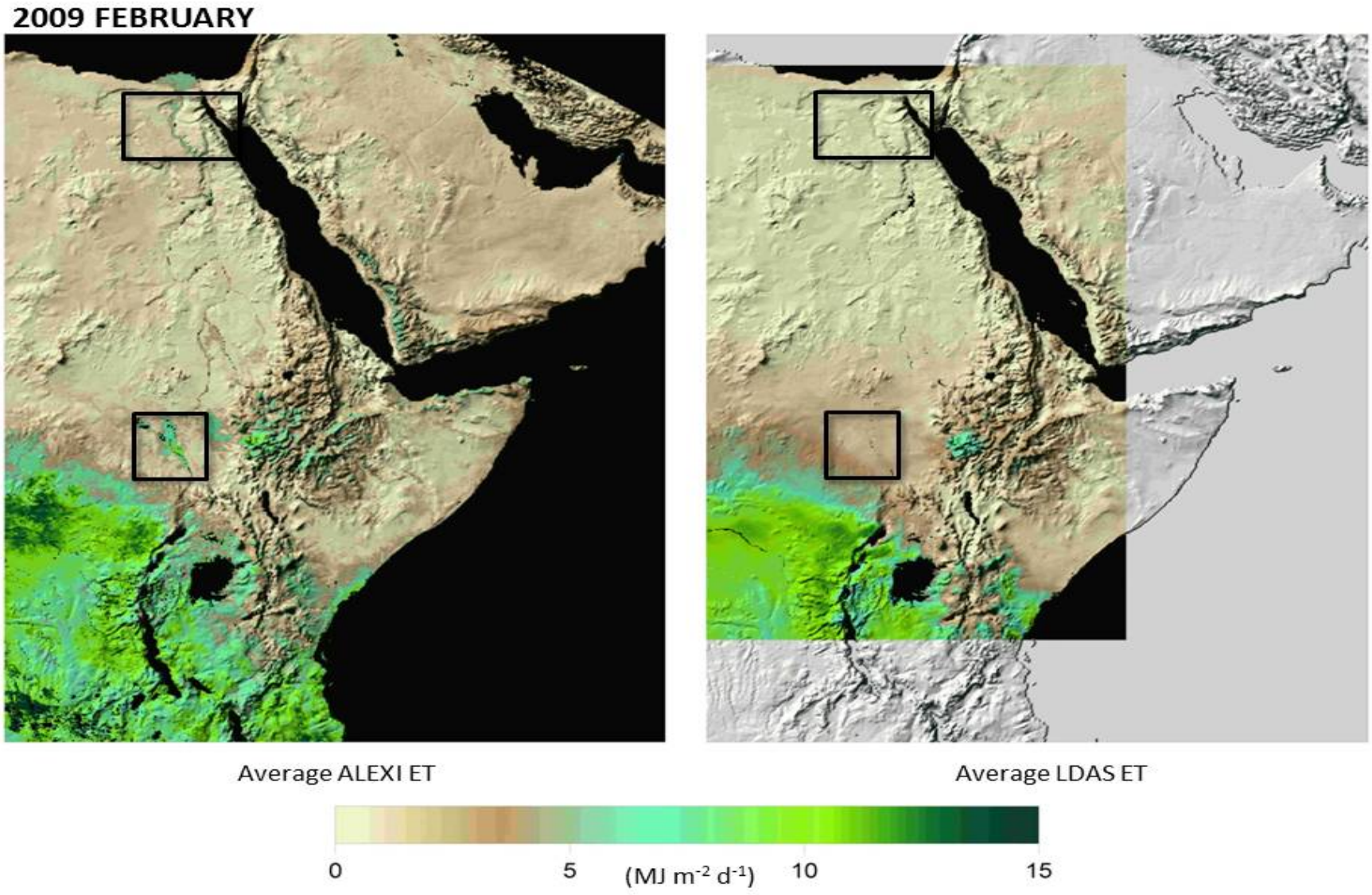


Drought Index of Actual ET/Pot'l ET (2007-2010)
Anderson/USDA



Source: David Toll, NASA Goddard Space Flight Center

Remotely Sensed ET may be used to improve modeling



Source: David Toll, NASA Goddard Space Flight Center

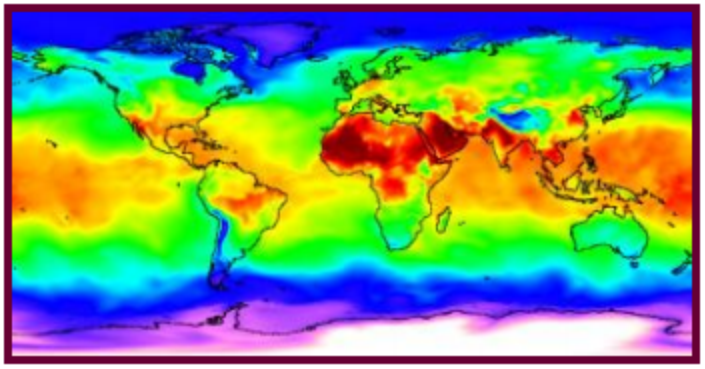
Examples of satellite derived ET products (not a comprehensive list)

- MODIS (MOD16, Global) – lower spatial resolution
- Landsat High Resolution and Interrelated Calibration (SEBAL/METRIC) (Regional/Local) – higher spatial resolution
- ET products via the Satellite Irrigation Management Support (SIMS) (Regional/Local to California) – higher spatial resolution

MODIS Based Global Evapotranspiration and Drought Severity Index Products

- Developed by Qiaozhen Mu, Maosheng Zhao, and Steven W. Running
- Numerical Terradynamic Simulation Group, College of Forestry and Conservation, The University of Montana Missoula
- Product name: MOD16
  http://www.ntsg.umt.edu/project/mod16

Input MODIS data (RS)
(Albedo, FPAR/LAI, Land cover)

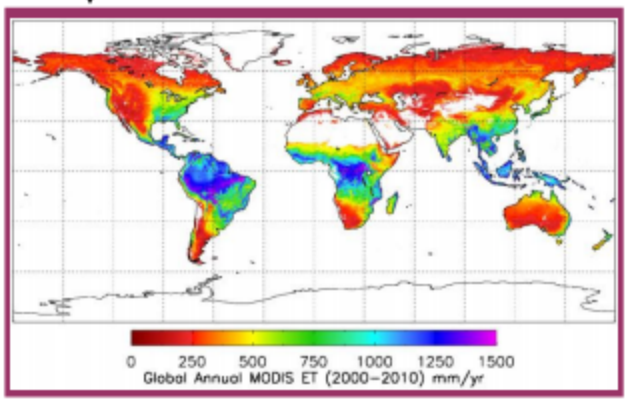


Daily Meteorological data (MET)
(S↓ , VPD, Temperature. No Prcp!)

Penman-Monteith equation

$$\lambda E = \frac{\Delta \bullet R_a \bullet (R_n - G) + \rho \bullet C_p \bullet VPD}{R_a \bullet (\gamma + \Delta) + \gamma \bullet R_S}$$

ET = f (RS, MET)



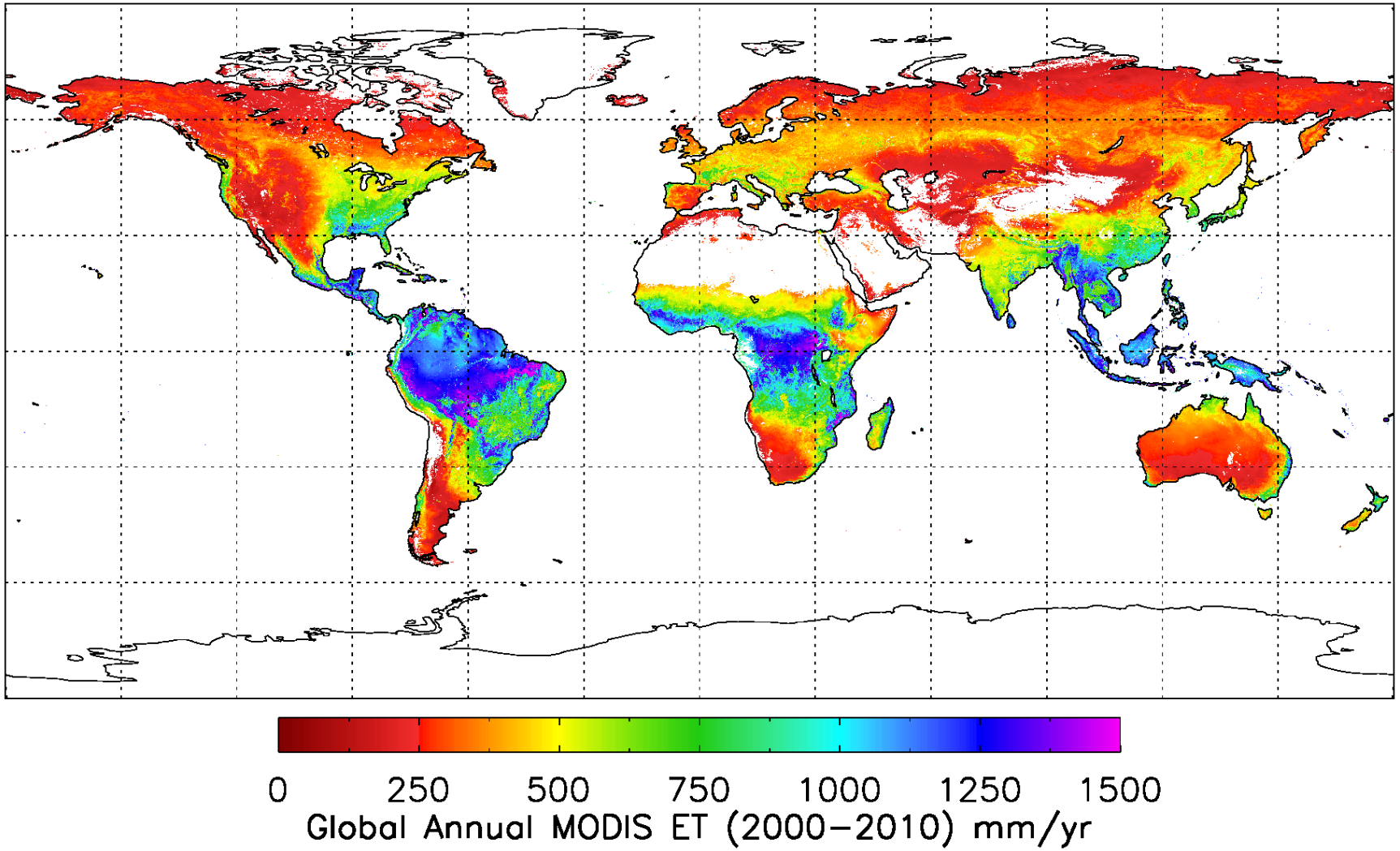
MODIS ET: soil evaporation, evaporation from intercepted water by canopy and plant transpiration.

Mu et al., 2007, RSE; Mu et al., 2011. RSE. Mu et al., 2009, WRR

Source: Qiaozhen Mu, University of Montana

Global annual 1-km ET over 2000-2010

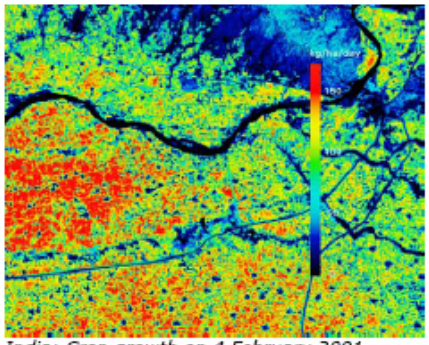
The Global average MODIS ET over vegetated land surface is 575.9 ± 381.6 mm yr^{-1}.



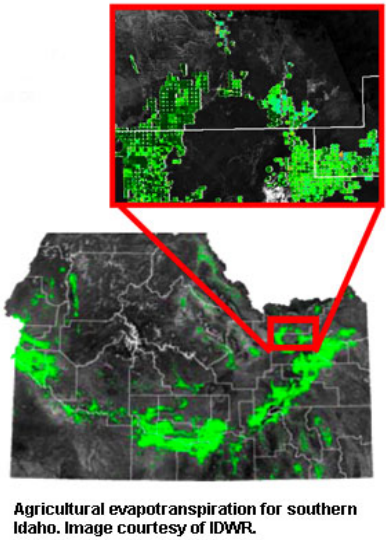
Source: Qiaozhen Mu, University of Montana

High Resolution Satellite-based ET: SEBAL and METRIC

- SEBAL – Bastiaanssen, WaterWatch
  - Used world-wide
  - Applications: ET and crop productivity
- METRIC
  - Univ. Idaho / Idaho Dept. Water Resources
  - Univ. Nebraska / DNR
  - New Mexico Tech.
  - Montana DNRC
  - Nevada DRI / NOSE
  - Colorado NCWCD / Riverside Tech.
  - World Bank - Morocco



India: Crop growth on 4 February 2001



Agricultural evapotranspiration for southern Idaho. Image courtesy of IDWR.

Source: Rick Allen, University of Idaho

Mapping EvapoTranspiration with high Resolution and Internalized Calibration (*METRIC^{tm}*)

- Rooted in the Dutch SEBAL^{2000} algorithms by Bastiaanssen· METRIC^{tm} and SEBAL are, in general, complementary processes
- Developed by Allen, Tasumi and Trezza , University of Idaho, Kimberly
- Landsat based algorithm
- Began in 2000

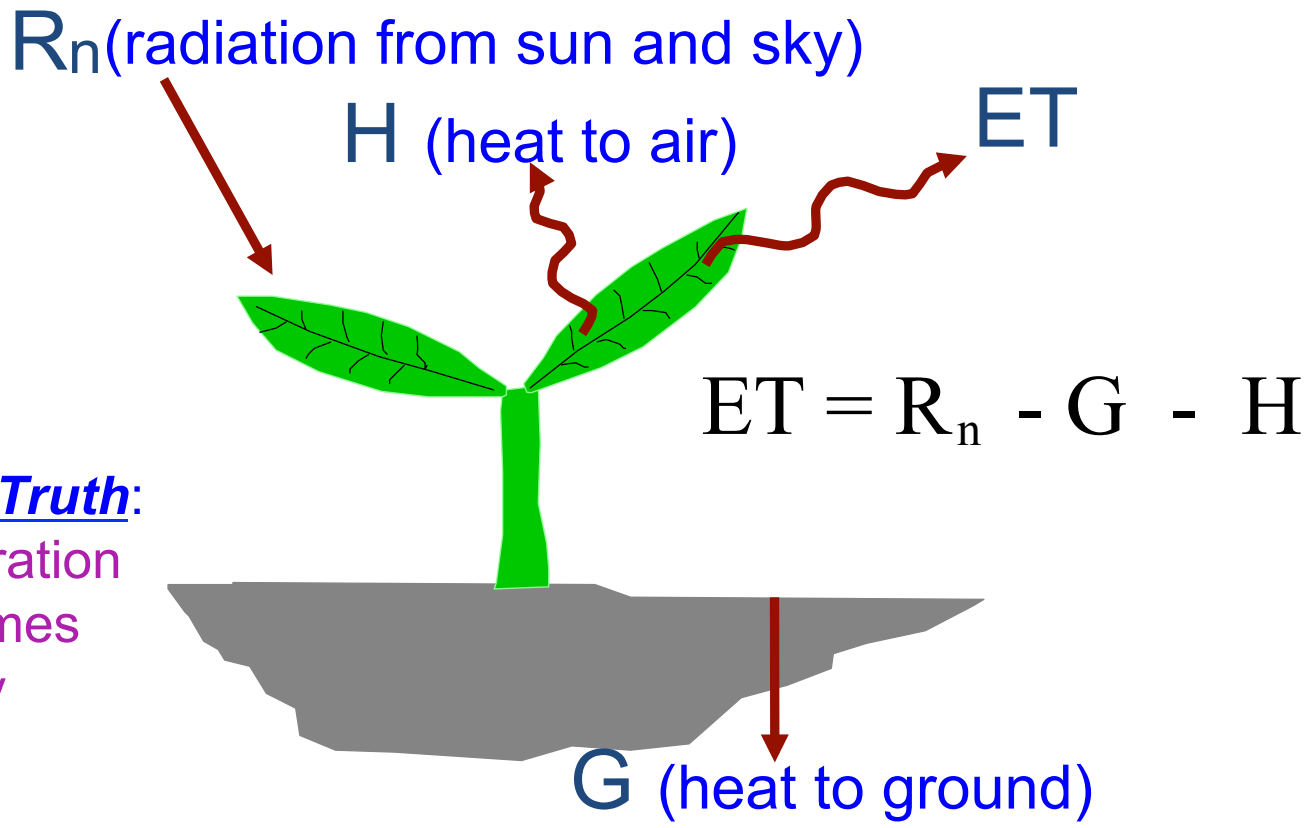
- Primary applications:

  Irrigated Agriculture
  Riparian Vegetation
  Desert Systems
  Wetlands

Source: Rick Allen, University of Idaho

Why Energy balance?

ET is calculated as a "residual" of the energy balance



$$ET = R_n - G - H$$

Basic Truth:
Evaporation consumes Energy

Source: Rick Allen, University of Idaho

Energy balance gives us “actual” ET

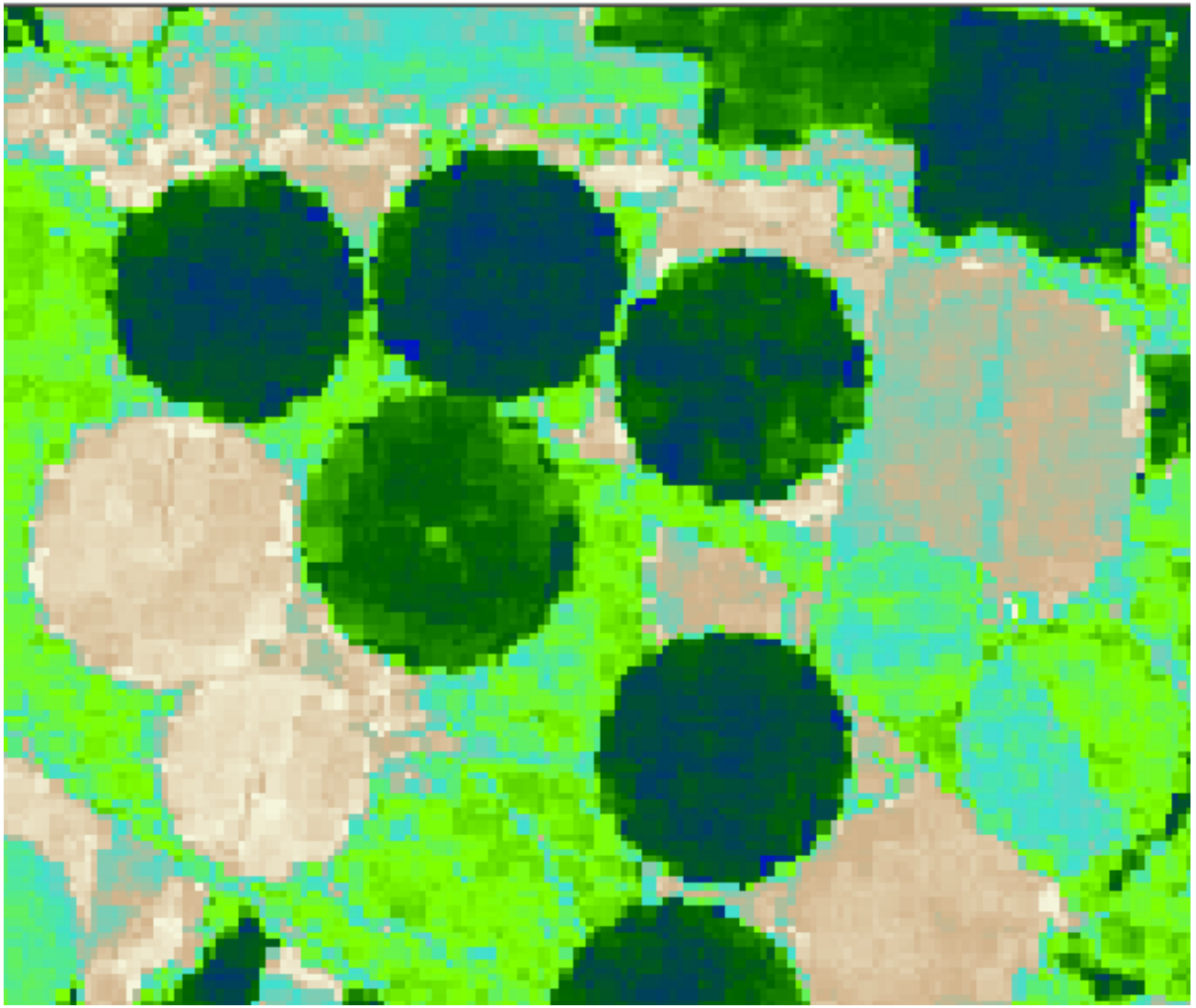
We can ‘see’ impacts on ET caused by:

- water shortage
- disease
- crop variety
- planting density
- cropping dates
- salinity
- management

- *Energy balance requires **THERMAL** information*
- *Many of these effects can be ‘missed’ by vegetation index based methods*
- *ET reduction effects can be converted directly into an evapotranspiration coefficient*

Source: Rick Allen, University of Idaho

Why use High Resolution Imagery?

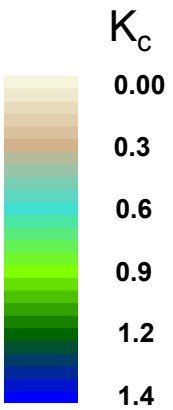


METRIC application in La Mancha, Spain, 2003

Source: Rick Allen, University of Idaho

ET from *individual* Fields is *Critical* for:

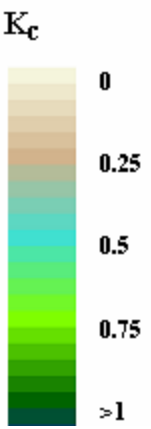
- Water Rights,
- Water Transfers,
- Farm Water Management



(K_c *based on* ET_o)

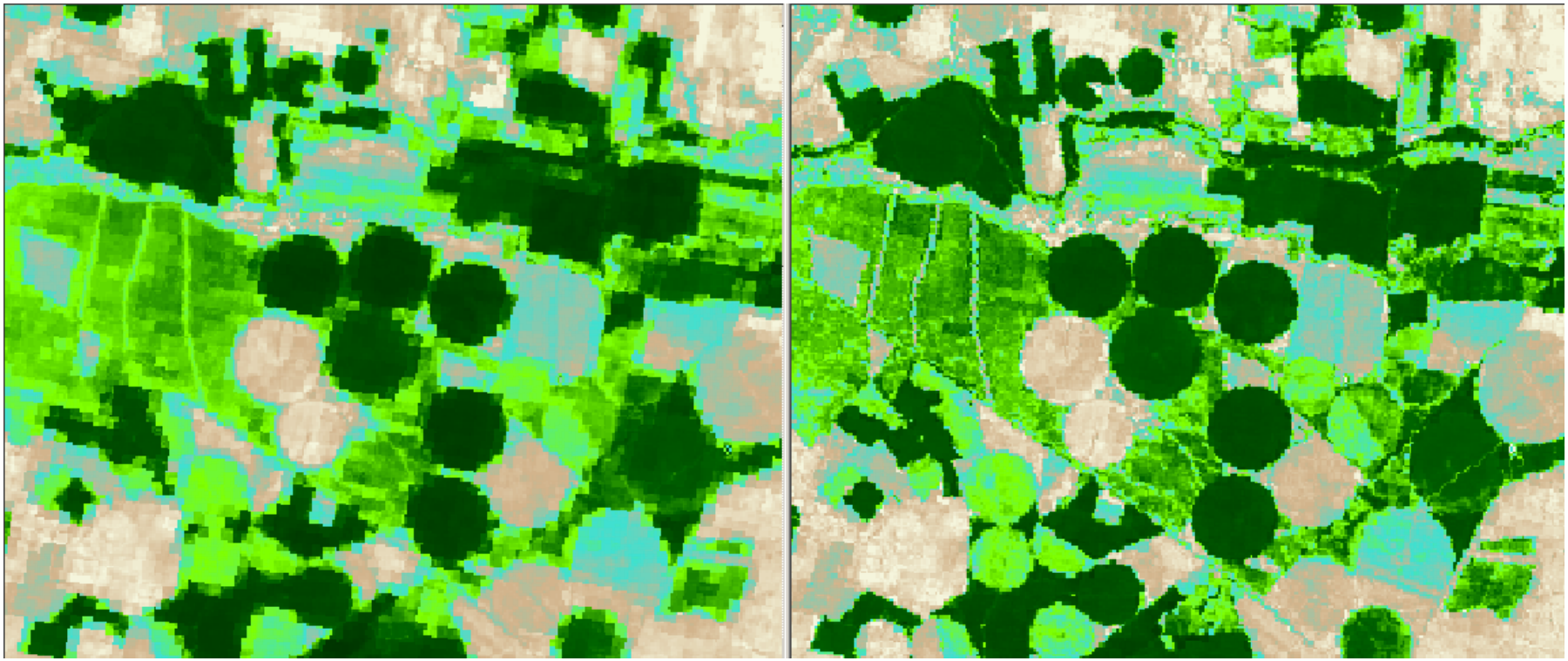
Sharpening of Thermal Band of Landsat 5 from 120 m to 30 m using NDVI

Landsat 5 -- Albacete, Spain, 07/15/2003



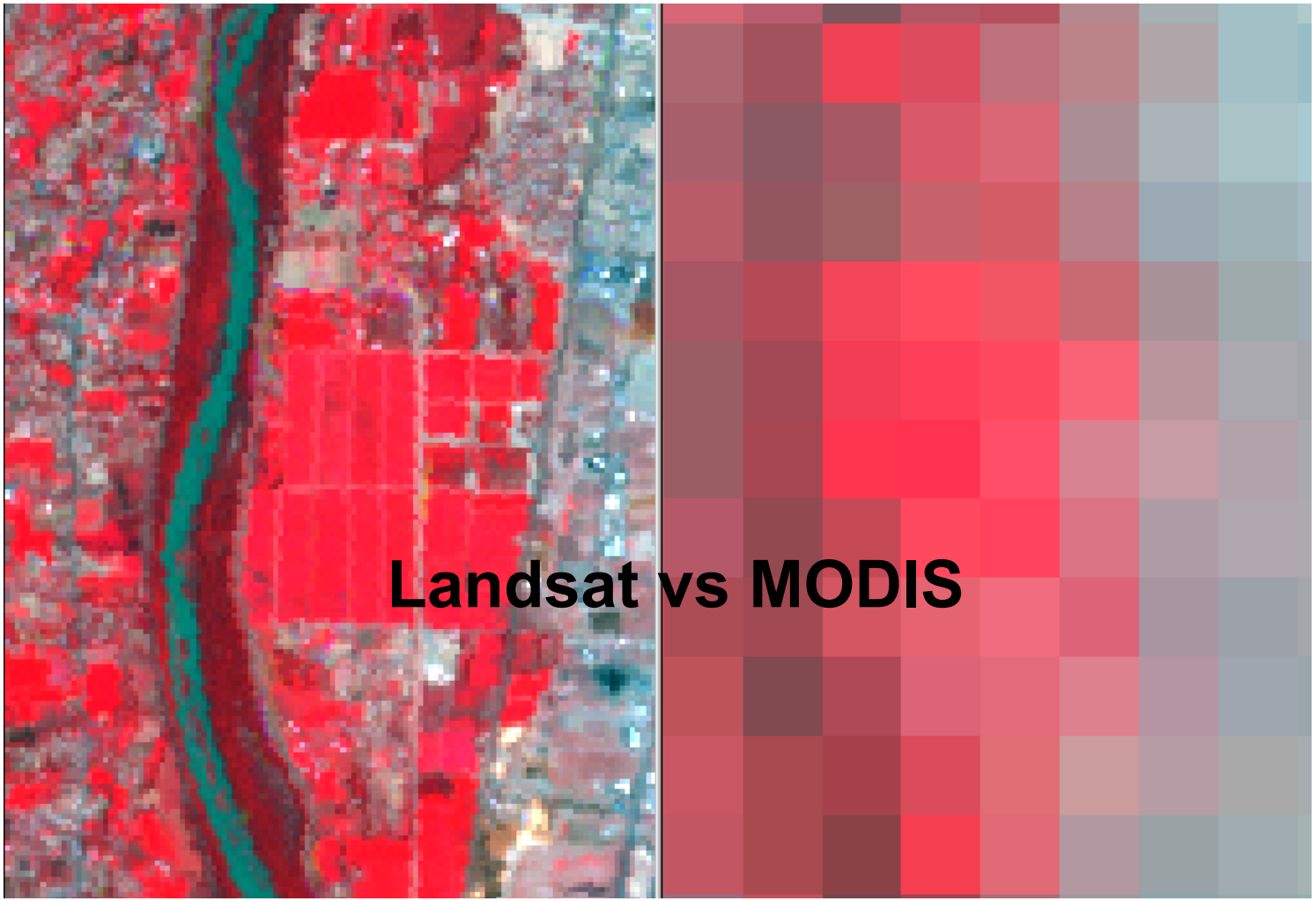
ET ratio before sharpening

ET ratio after sharpening



Source: Rick Allen, University of Idaho

Why use High Resolution Imagery?

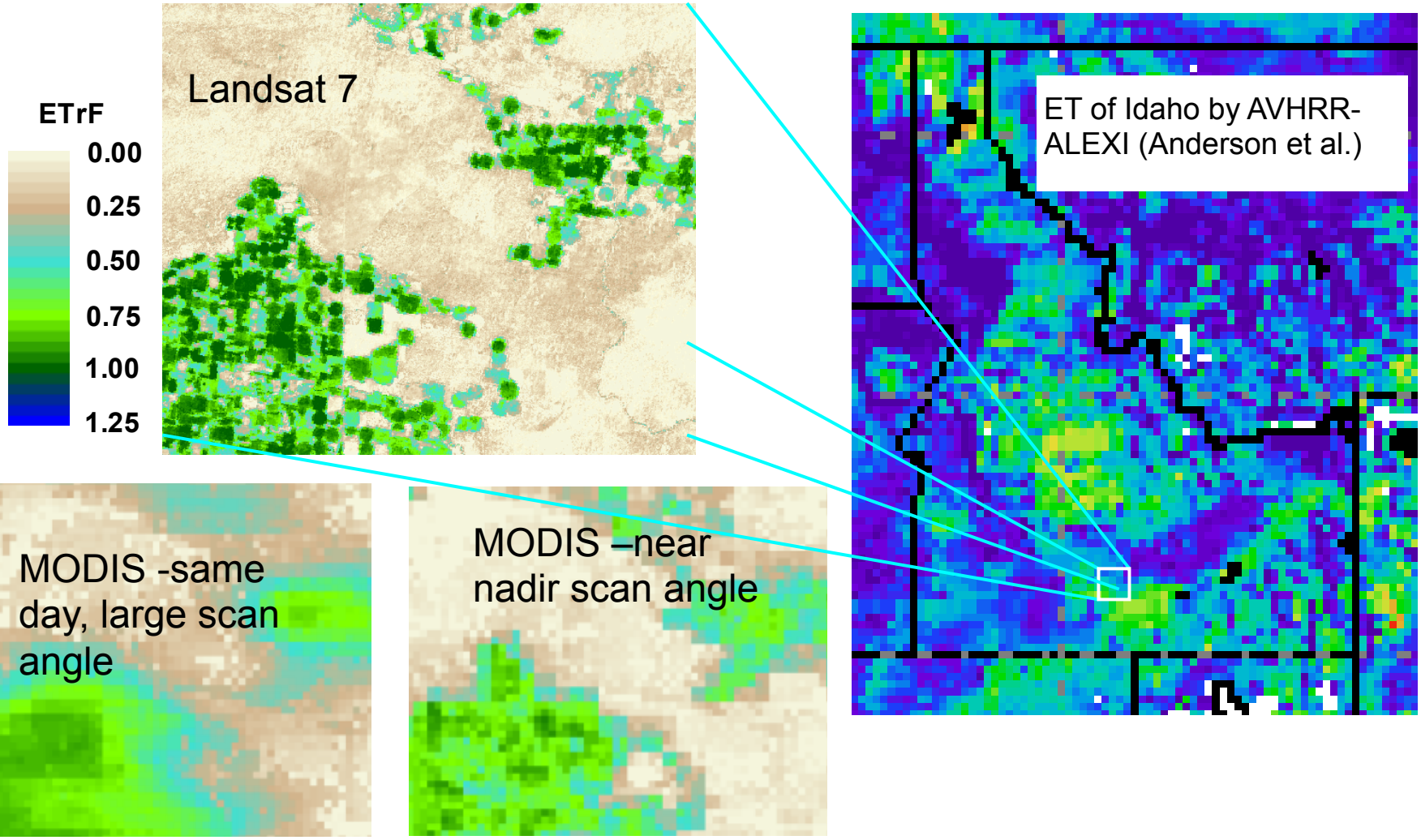


Landsat False Color (MRG)
8/26/2002 10:33am

MODIS False Color (MRG)
8/26/2002 11:02am

Source: Rick Allen, University of Idaho

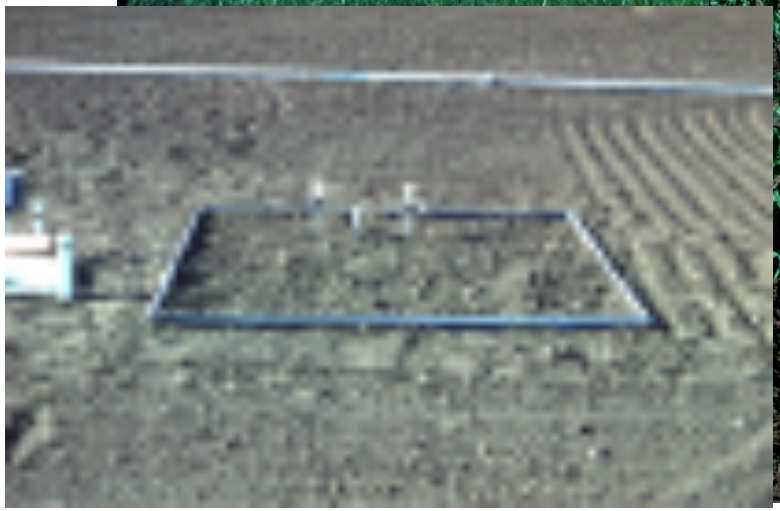
Why use High Resolution Imagery?



Source: Rick Allen, University of Idaho

Comparison of Metric and Lysimeter Measurements:

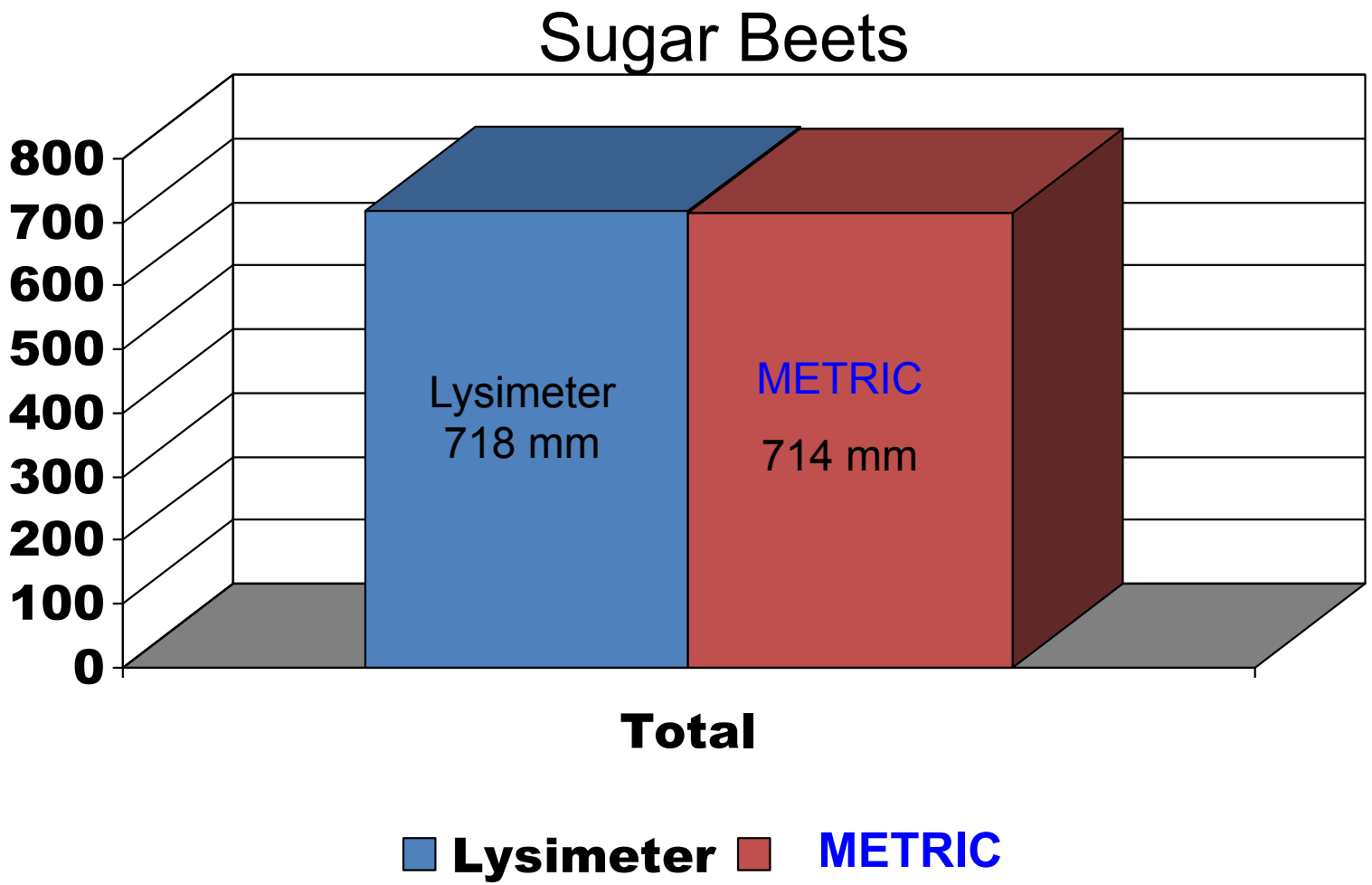
1968-1991



Source: Rick Allen, University of Idaho

Comparison of Seasonal ET by METRIC^{tm} with Lysimeter Measurements

ET (mm) - April-Sept., *Kimberly, 1989*



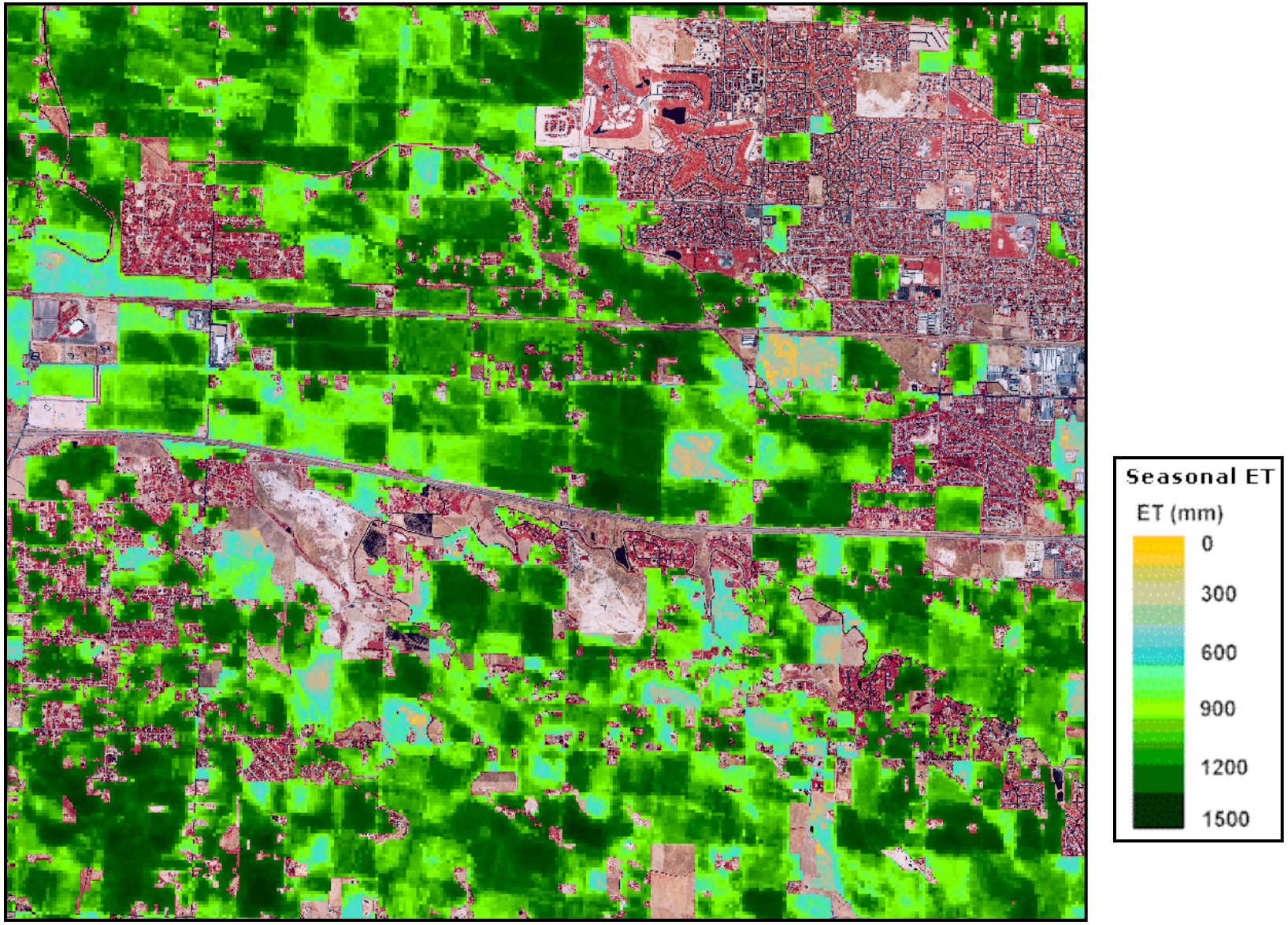
Source: Rick Allen, University of Idaho

METRIC ET Applications at the Idaho Department of Water Resources

1. Aquifer depletion
2. Water rights buy-back
3. Planning: ET by land use class
4. Water use by irrigated agriculture
5. Water rights compliance monitoring
6. Modeling: ET for computing water budgets
7. Analysis of water-rights curtailment alternatives.

Source: Rick Allen, University of Idaho

Metric: Agricultural Water Use



Source: Rick Allen, University of Idaho

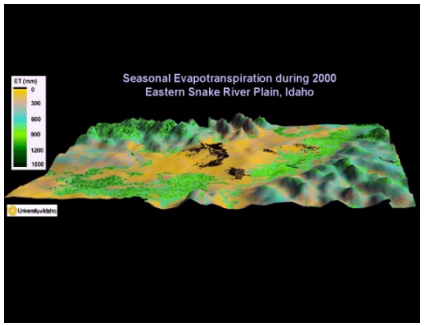
Metric: Agricultural Water Use

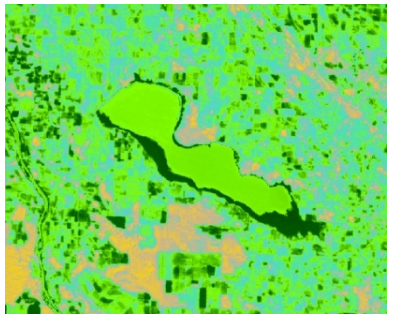
RESULTS

Year	Water Use in Acre Feet	Irrigated Hectares	Mean Water Use in Millimeters	Source
2000	**9,313,505**	**1,437,520**	**790 -** 1021 Alfalfa (.77)	**IDWR/METRIC**
2002	--	1,176,516	--	Census of Agriculture
2000	--	1,367,859	--	USGS
1997	--	1,241,522	--	Census of Agriculture
1995	4,396,707	1,097,225	490 (807 Alfalfa) (.61)	USGS
1992	--	1,169,710	--	Census of Agriculture
1990	6,817,991	1,235,348	670 (957 Alfalfa) (.70)	USGS/IDWR
1987	--	1,146,018	--	Census of Agriculture

Source: Rick Allen, University of Idaho

ET from Metric: Summary

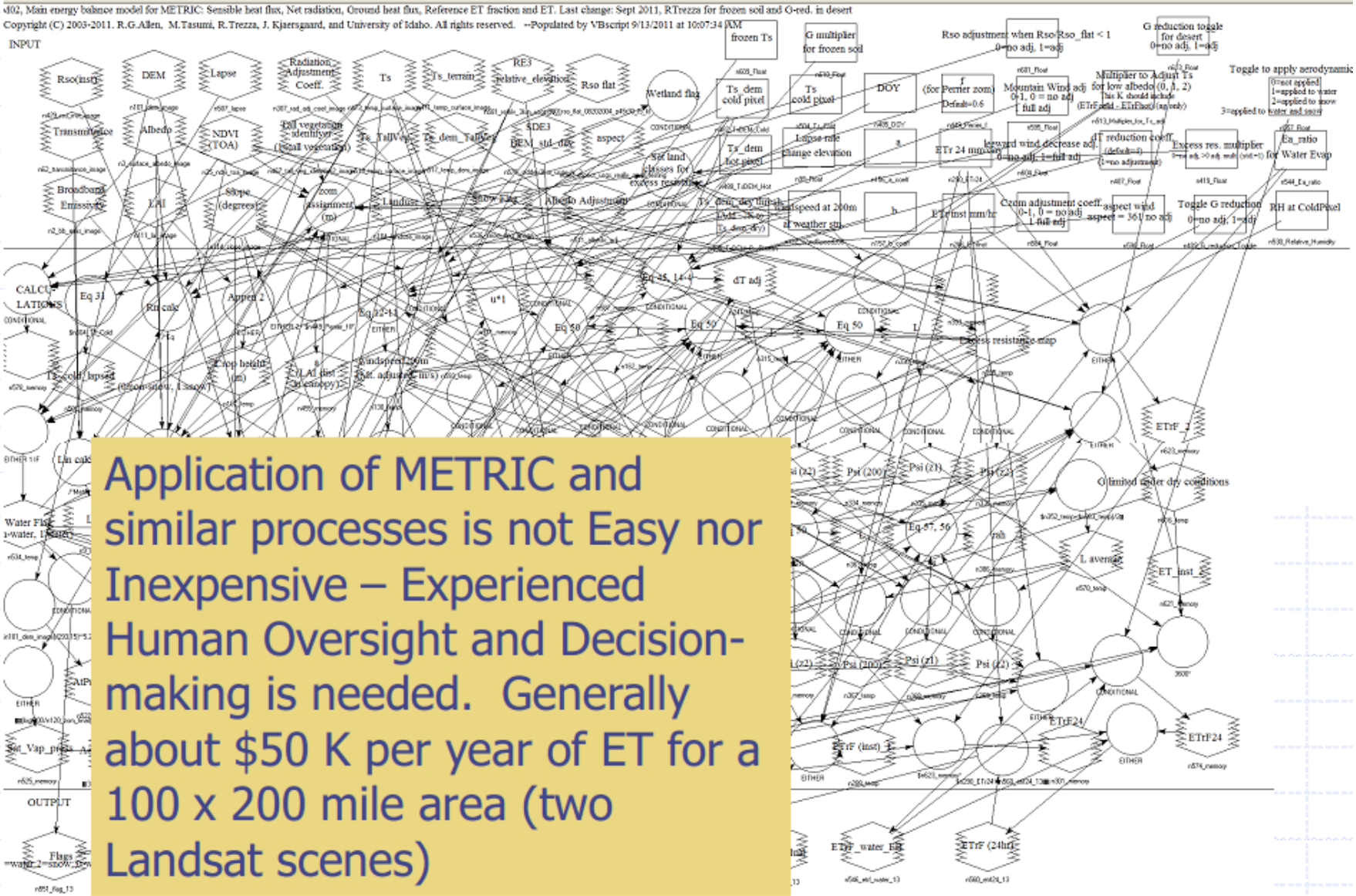




- ET maps are valuable for:
  - Determining **Actual** ET
  - Water Transfers
  - Water Rights Conflicts
  - Diversion Management for Endangered Species
  - Ground-water Management
  - Consumption by Riparian Vegetation
- ET maps by METRIC^{tm} (and SEBAL) have good accuracy and consistency
- A single, high resolution ***thermal band*** is ***adequate and essential***

Source: Rick Allen, University of Idaho

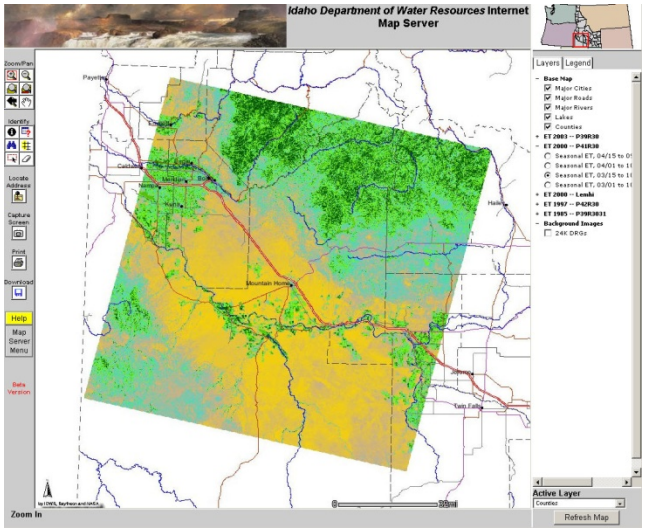
'full' METRIC^{tm}-ERDAS submodel for sensible heat and ETrF



Source: Rick Allen, University of Idaho

Metric:
Additional Information

- www.kimberly.uidaho.edu/water/ (METRIC^{tm})
- http://www.idwr.idaho.gov/gisdata/et.htm
- http://maps.idwr.idaho.gov/et/



Source: Rick Allen, University of Idaho

Satellite Irrigation Management Support (SIMS) with the NASA Terrestrial Observation and Prediction System (TOPS)

Project Team:
Forrest Melton, Lee Johnson, Chris Lund, Lars Pierce, Rama Nemani, Andrew Michaelis, Alberto Guzman, Sam Hiatt, Ian Harlan, AJ Purdy, Carolyn Rosevelt, Noelle Fletcher, Thor Anderson, Hirofumi Hashimoto, Ed Sheffner

Ecological Forecasting Lab
CSU Monterey Bay & NASA Ames Research Center
Moffett Field, CA

Collaborators from:
California Department of Water Resources, USDA Agricultural Research Service, Western Growers, Del Monte Produce, Constellation Wines, CSU Fresno, Davids Engineering, NOAA NWS, USGS

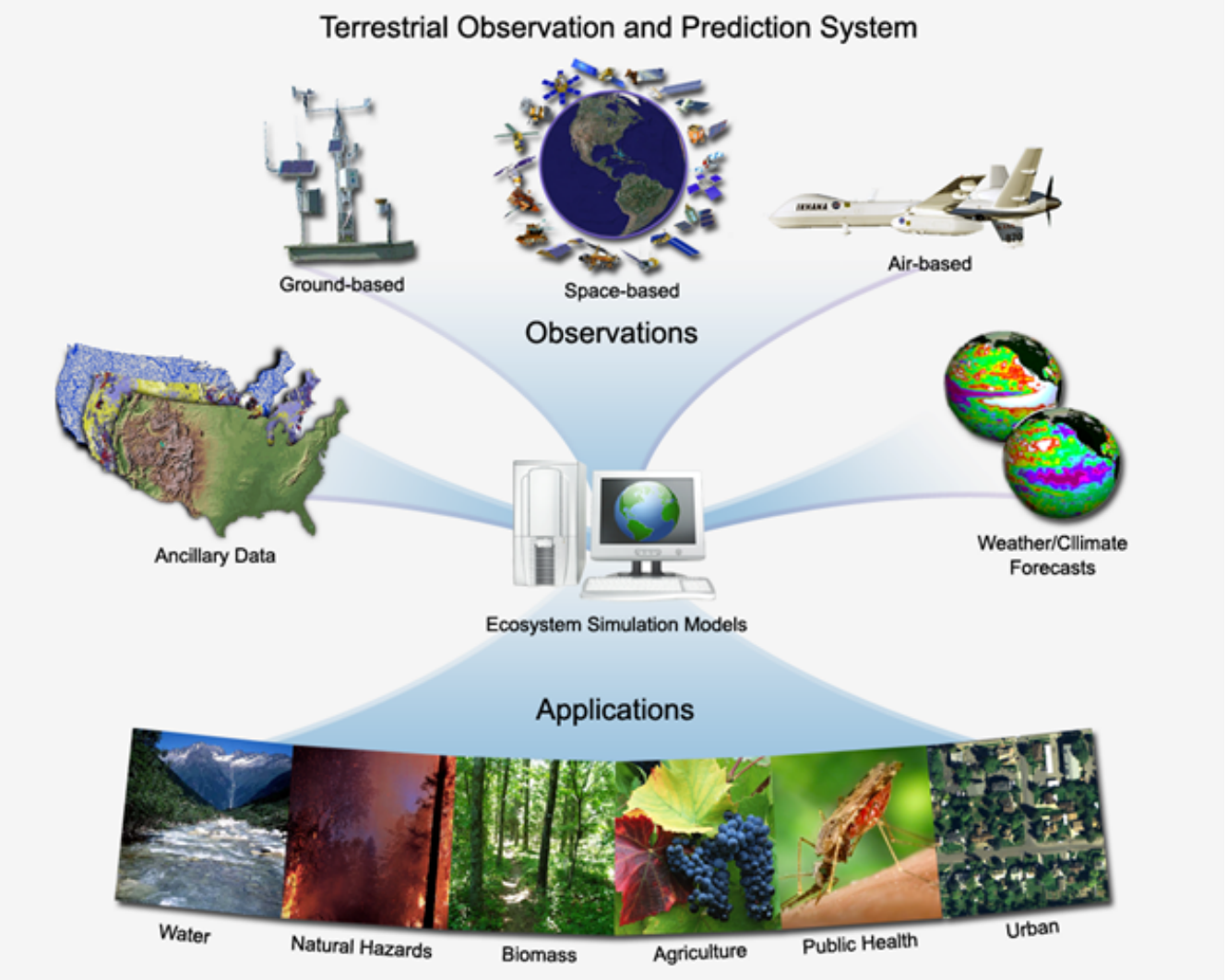
Support for this project provided by the NASA Applied Sciences Program

TOPS provides multi satellite based ecological nowcast and forecast

Source: Forrest Melton, CSUMB/NASA

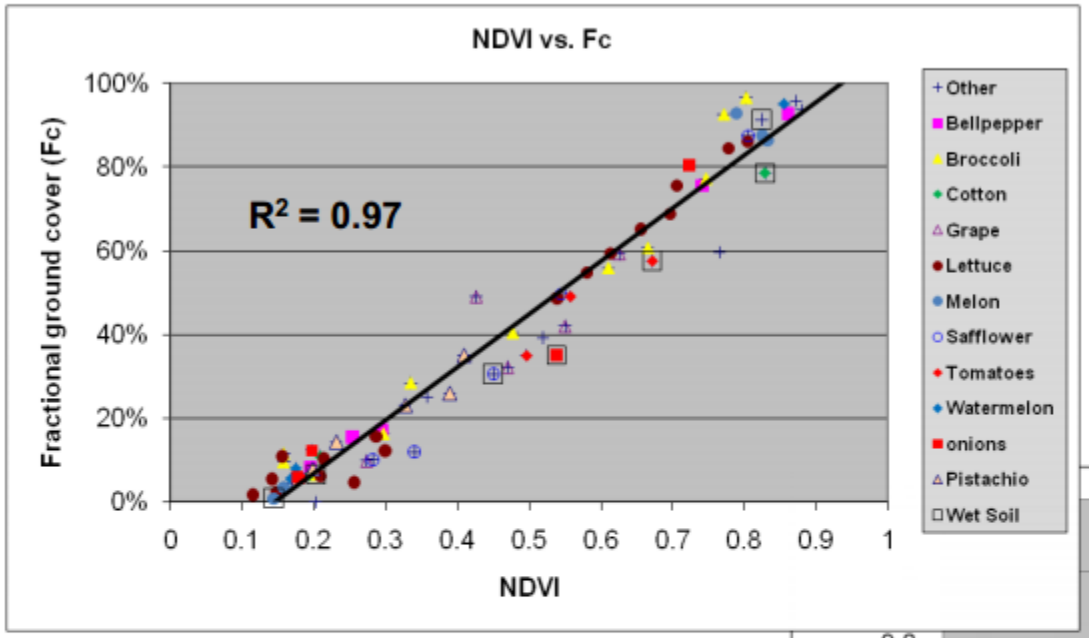
TOPS: Common Modeling Framework

Monitoring, modeling, & forecasting at multiple scales



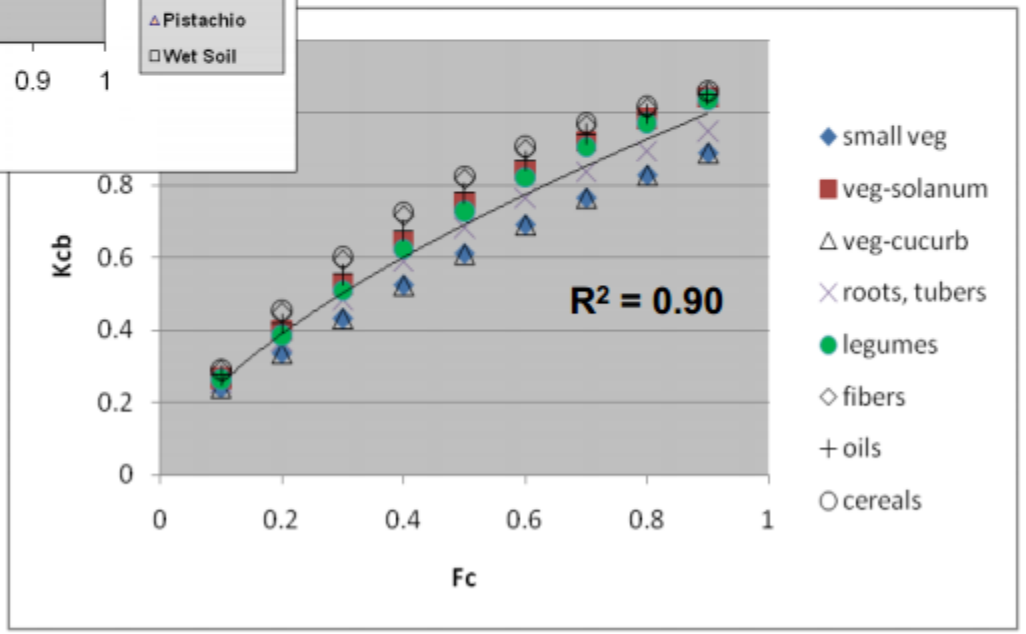
Nemani et al., 2003, 2007, 2008

Mapping Crop Coefficients from Satellite Data



Trout et al., 2008; Johnson & Trout, in review

USDA studies provide basis for linking NDVI to fractional cover.



Recent studies by Allen & Pereira (2009) and others provide basis for linking fractional cover to Kcb for a range of crops. *Additional studies ongoing in collaboration with CSU Fresno and UC West Side Research & Extension Center*

Also see Bryla et al., 2010; Grattan et al., 1998; Hanson & May, 2006; Lopez-Urrea et al., 2009

Source: Forrest Melton, CSUMB/NASA

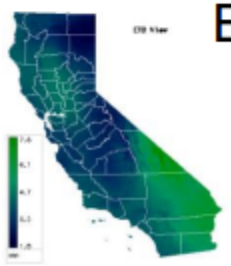
Integration of Satellite and Surface Observations Networks to estimate ET

- Builds on the California Irrigation Management Information System (**CIMIS**)
  - Operating since 1982
  - Currently 139 stations
  - Recent addition of 2km statewide ET_0 grids

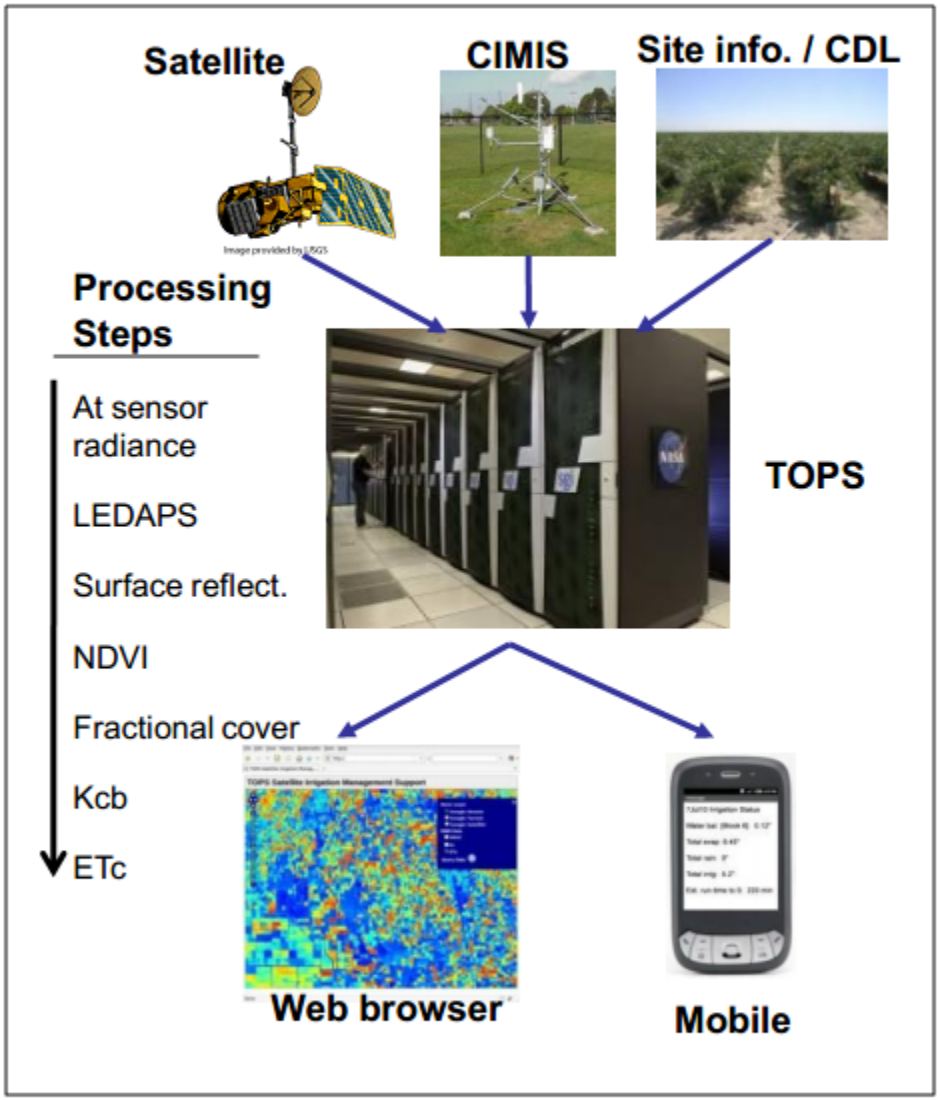
- Standard approach for incorporating weather information into irrigation management practices

$$ETcb = ETo * Kcb$$

CIMIS satellite



Spatial CIMIS ET_0
March 31, 2011



Integration of satellite and surface observation networks

Source: Forrest Melton, CSUMB/NASA

ET Information Product Requirements

Requirements for Kcb/ETcb mapping (from workshops with growers):

- **Timely:** available within 24-48 hours of satellite overpass (system must be fully automated)
- **Frequent:** ETc updated daily, Kc updated at least every 8-16 days
- **High resolution:** must provide multiple measurements per field for fields 5 acres or larger
- **Accessible / easy to use:** quantitative information available via web browsers, mobile phones

Source: Forrest Melton, CSUMB/NASA

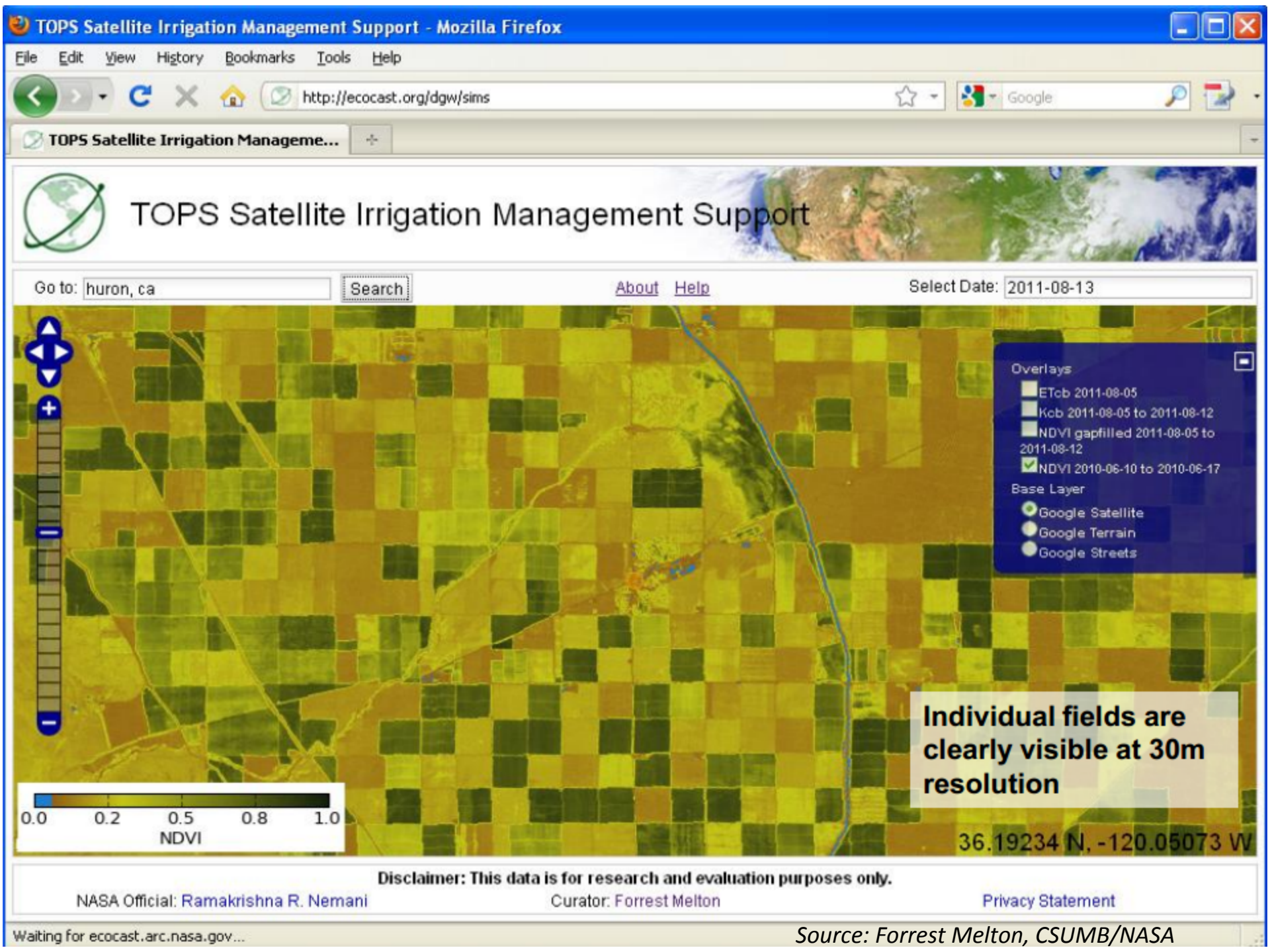
Access to TOPS

TOPS website

http://ecocast.arc.nasa.gov/sims/

TOPS website for data access (beta)

http://www.ecocast.org/dgw/sims



Source: Forrest Melton, CSUMB/NASA

Summary: TOPS-SIMS

- TOPS-SIMS: Fully automated system for near real-time satellite data processing & mapping of NDVI, F_c, K_{cb}, & ET_{cb}
- Web interface for data access and retrieval
- Comparison against other ET models, surface renewal measurements / soil moisture data ongoing; initial results encouraging
- Next Steps:
  - Currently working with partner growers to test web interface and develop additional information tools
  - Continuing work on comparison with other models and surface observations of ET
  - Integration of other satellite-driven models and NOAA FRET data
  - Working with partners to develop plans for long term operational support

Source: Forrest Melton, CSUMB/NASA

Conclusions

- Deriving ET is a complex process.
- ET is not directly measured.
- There are multiple ET products available that utilize different approaches and remote sensing instruments.
- High resolution thermal imaging is critical